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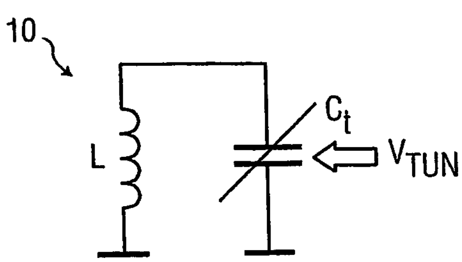
(54) Title: TUNABLE TRACKING FILTER



(57) Abstract: An integrated tuner circuit (20) with an arbitrary IF output. The tuner includes an integrated circuit with a fixed-frequency control loop (30) and a matched external variable capacitance C_t, to achieve tracking of a tuned LC band-pass filter (10) with an arbitrary oscillator.

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TUNABLE TRACKING FILTER

The present invention relates in general to an integrated tuner circuit, e.g., for use in televisions and radios, and more particularly, to the tracking of a tuner filter with an arbitrary oscillator.

Tuner technology has evolved to the point where a tuner for a television signal receiver, radio, etc., can now be formed on a single integrated circuit. Currently available integrated tuners are generally application specific, i.e., the tuners are designed for operation using specific oscillator and intermediate (IF) frequencies. Thus, different integrated tuners may be required for different RF applications.

The present invention provides an integrated tuner circuit with an arbitrary IF output. The tuner includes an integrated circuit (IC) control loop, and matched external variable capacitance C_t, to achieve tracking with an arbitrary oscillator.

These and other features of this invention will be more readily understood from the following detailed description of the various aspects of the invention taken in conjunction with the accompanying drawings in which:

FIG. 1 illustrates a tuned LC band-pass filter with variable capacitance C_t and fixed inductance L.

FIG. 2 illustrates a variable external load capacitance C_t and the tuned LC band-pass filter of FIG. 1.

FIG. 3 is a block diagram of an integrated tuner circuit including a fixed-frequency control loop for filter tracking in accordance with the present invention.

It should be noted that the drawings are merely schematic representations, not intended to portray specific parameters of the invention. The drawings are intended to depict only typical aspects of the invention, and therefore should not be considered as limiting the scope of the invention.

A tuned LC band-pass filter 10 is illustrated in FIG. 1. The band-pass filter 10 comprises a variable total capacitance C_t and an inductive coil L arranged in parallel. The band-pass filter 10 is tuned by a tuning voltage V_{TUN}, which is applied to a varicap diode (not shown) coupled to the band-pass filter 10. When L is fixed, the resonant frequency ω_{tank} of the band-pass filter 10 is given by:

$$\omega_{tank} = \omega_{LO} \pm \omega_{IF} \qquad \text{(EQU. 1)}$$

or:

$$\omega_{tank}^2 = 1/LC_t. \qquad \text{(EQU. 2)}$$

This implies that:

$$\omega_{tank}^2 C_t = 1/L = \text{constant}, \qquad \text{(EQU. 3)}$$

which leads to:

$$C_t :: \omega_{tank}^{-2} = (\omega_{LO} \pm \omega_{IF})^{-2}, \qquad \text{(EQU. 4)}$$

which is the frequency-dependent relation that is needed for tracking.

In a frequency-synthesized tuner that includes such a band-pass tuner filter 10, the local oscillator frequency ω_{LO} of the tuner, which is applied at a mixer, relates to a reference X-tal oscillator frequency ω_{xtal} via:

$$\omega_{LO} = N_{div}/M_{div}\ \omega_{xtal} \qquad \text{(EQU. 5)}$$

where M_{div} is a fixed-frequency-divider ratio, and N_{div} is a programmable frequency divider. Given a fixed reference X-tal oscillator frequency ω_{xtal}, then EQU. 5 implies that:

$$\omega_{LO} :: N_{div}, \qquad \text{(EQU. 6)}$$

which also implies from EQU. 1 that for zero- or low-IF:

$$\omega_{tank} = (\omega_{LO} \pm \omega_{IF}) :: N_{div} \qquad \text{(EQU. 7)}$$

For a zero-IF tuner concept, the resonance frequency ω_{tank} of the band-pass filter 10 equals the local oscillator frequency ω_{LO} of the tuner for proper tracking. For a near-zero IF concept $\omega_{tank} \approx \omega_{LO}$ and consequently, from EQU. 4:

$$C_t :: \omega_{LO}^{-2}. \qquad \text{(EQU. 8)}$$

From EQU. 7, this leads to:

$$C_t :: N_{div}^{-2}. \qquad \text{(EQU. 9)}$$

For a low-IF IC-concept (e.g., near-zero or zero-IF), the oscillator or divided oscillator frequency can, for example, be offered via a current source to an external load capacitor C_t, which is matched with the capacitance C_t in the band-pass filter 10. An integrated tuner circuit 20 including the band-pass filter 10 and an external load capacitor C_t is illustrated in FIG. 2. The integrated tuner circuit 20 includes an integrated circuit 22 having a control loop (not shown) for producing the tuning voltage V_{TUN}. The external load capacitor C_t is tuned by the tuning voltage V_{TUN}, which is applied to a varicap diode (not shown) being part of the external load capacitor C_t. Defining the voltage across the external capacitor C_t as:

$$u_t(t) = N_{div}^2 U_t \cos\omega_{xtal} t, \qquad \text{(EQU. 10)}$$

it follows that:

$$i_t(t) = -\omega_{xtal} C_t N_{div}^2 U_t \sin\omega_{xtal} t. \qquad \text{(EQU. 11)}$$

By making $i_t(t)$ amplitude independent of N_{div} and C_t, then:

$$C_t :: N_{div}^{-2} \qquad \text{(EQU. 12)}$$

Thus, the capacitance the external load capacitor C_t and the capacitor C_t in the band-pass filter 10 are both proportional to N_{div}^{-2}. As such, in case of tracking between an oscillator in a zero- or low-IF frequency concept and a varicap-tuned LC band-pass filter 10 with fixed L and variable C_t, the integrated tuner circuit 20 can generate a very well defined oscillator-frequency related voltage across the matched load capacitor C_t. Conversely, in case of no tracking, the voltage will deviate from the predicted oscillator frequency dependent behavior. If, in that case the integrated tuner circuit 20 would generate a tuning voltage V_{TUN} for the capacitor C_t of the band-pass filter 10 as well as the external load C_t, a control loop can be defined such that the (frequency divided) oscillator voltage across C_t behaves as needed for tracking. The control loop will ensure that the frequency-dependent behavior for the oscillator and band-pass filter 10 is the same, which means that band-pass filter 10 and the oscillator will de-tune with the same factor all the time.

In the above-described approach, it is assumed that the external load capacitor C_t is the only external load to the integrated tuner circuit 20. However, the integrated tuner circuit 20 will also add additional capacitive load, which will

cause tracking errors especially at the higher end of the frequency band, where C_t becomes small. The added capacitance (i.e., parasitic capacitance C_p) is determined by the integrated tuner circuit 20 package as well as by on-chip capacitance. Since the value of C_p can be estimated beforehand during design of the integrated tuner circuit, compensation in the control loop 30 can be taken into account.

The present invention provides a fixed-frequency control loop 30 (FIG. 3) for tuning the capacitance C_t of the band-pass filter 10 such that the band-pass filter 10 keeps tracking with a virtually-variable oscillator frequency (i.e., a frequency that need not be present in the integrated tuner circuit 20), after alignment (if necessary) at one frequency point. The control loop 30 is located within the integrated tuner circuit 20, while the band-pass filter 10 and external load capacitance C_t are located outside the integrated tuner circuit 20. The resonance frequency ω_{tank} of the band-pass filter 10 is approximately equal to $\omega_{LO} \pm \omega_{IF}$.

In view of the above analysis, the control loop 30 has been designed to produce a signal having a relevant component given by the expression:

$$1 - (\alpha\omega_{xtal}^2R^2C)N^2C_t. \qquad \text{(EQU. 13)}$$

where α is a variable gain, ω_{xtal} is the X-tal oscillator 32 frequency, R is a resistance, C is a capacitance, and N is a programmable value proportional to N_{div} for setting the value of ω_{LO}. N_{div} has been converted into N, because N_{div} is usually a 15 bit number, which enables small oscillator steps, but the band-pass filter 10 steps are allowed to be much larger and consequently N can be limited to, e.g., a seven bit word proportional to N_{div}. From EQU. 7, therefore:

$$\omega_{LO} \approx \omega_{tank} \Leftrightarrow N_{div} \approx N. \qquad \text{(EQU. 14)}$$

Both previous equations ($\omega_{LO} :: N_{div}$ (EQU. 6) and $\omega_{tank} = (\omega_{LO} \pm \omega_{IF}) :: N$ (EQU. 7)) are valid and implicitly an ω_{LO} and ω_{IF} dependent relation between N and N_{div} follows. By programming N and N_{div} accordingly, tracking is obtained. In case of zero- or low-IF, $N_{div} \approx N$ will be sufficient for tracking.

In EQU. 13, N and C_t are the only oscillator frequency dependent components. As such, as long as $\omega_{LO} :: N_{div} \approx N$, the capacitance C_t will be tuned such that:

$$1 - (\alpha\omega_{xtal}^2R^2C)N^2C_t \rightarrow 0 \quad \text{(EQU. 15)}$$

to ensure that the band-pass filter 10 keeps tracking with the desired oscillator frequency.

In the control loop 30, the output U_0 of oscillator 32 is passed through an analog multiplying circuit 34 of a type known in the art to produce a signal U_0N^2. For example, as illustrated in FIG. 3, the analog multiplying circuit 34 may comprise two identical cascaded amplifiers with programmable gain. It should be noted that N and U_0N^2 may also be provided digitally. The value N corresponding to the desired tuning oscillator frequency ω_{LO} of the band-pass filter 10 is provided to the multiplying circuit 34 via software or hardware control. The signal U_0N^2 is passed through adjustable gain circuit 36 into a stage 38 designed to produce a signal 40 given by:

$$-U_0\{1 - \alpha N^2(j\omega_0RC - \omega_{xtal}^2R^2CC_p)\}. \quad \text{(EQU. 16)}$$

A feedback stage 42 is provided to produce a signal 44 given by:

$$-\alpha N^2U_0\{j\omega_{xtal}RC - \omega_{xtal}^2R^2C(C_t + C_p)\} \quad \text{(EQU. 17)}$$

In the block diagram, it is assumed that compensation for the parasitic capacitance C_p of the integrated circuit 20 has been provided during the integrated circuit design phase and, as such, C_p appears in stage 38 and in parallel to the external load capacitance C_t.

The circuit analysis for deriving the expressions presented in EQUS. 16 and 17 from stages 38 and 40, respectively, is assumed to be within the scope of those skilled in the art and will not be presented in detail herein. Also, it should be appreciated that the expressions presented in EQUS. 16 and 17 may be provided using analog and/or digital circuitry other than that disclosed herein and illustrated in FIG. 3.

The signals 40, 44 presented in EQUS. 16 and 17, respectively, are combined in an adder 46, resulting in a signal 48 given by:

$$-U_0\{1 - (\alpha\omega_{xtal}^2R^2C)N^2C_t\}. \quad \text{(EQU. 18)}$$

After mixing 50 the signal 38 with the oscillator 32 signal, and integrating 52 to a tuning voltage V_{TUN}, C_t is controlled such that the expression presented in EQU. 13, namely, $1 - (\alpha\omega_{xtal}^2R^2C)N^2C_t \rightarrow 0$, is realized. Consequently, C_t :: $(\omega_{LO} \pm$

$\omega_{IF})^{-2}$, or $C_t :: \omega_{LO}^{-2}$ for zero- and low-IF, which are the frequency dependent relations needed for tracking.

In the present invention, the fixed-frequency control loop 30 uses the value N, which is approximately equal to the frequency division ratio N_{div}, for oscillator tuning without using the actual oscillator frequency ω_{LO} itself. In the high-IF case where the ratio N, used for tuning the band-pass filter 10 tracking, does not correspond with N_{div} (i.e., $N_{div} \neq N$), the band-pass filter 10 may be tuned to a frequency different from the than the desired oscillator frequency ω_{LO}. In this case, separate programming is required for N_{div} and N. However, after a single alignment, the frequency to which the band-pass filter 10 is tuned is accurately known for each value of N. The alignment may be accomplished via the variable gain α provided by the adjustable gain circuit 36, and/or by adjusting the fixed value of the inductor L in the band-pass filter 10. Alternately, or in addition, for a small frequency offset between the band-pass filter 10 and the oscillator frequency ω_{LO}, some mismatch can be given to the external load capacitance C_t relative to the capacitance C_t in the band-pass filter 10. Consequently, by independently addressing the values for N, the band-pass filter 10 can be tuned to each wanted IF distance from the desired oscillator frequency ω_{LO}. It should be noted that for non-zero concepts, a frequency offset may also be realized by adaptation of the voltage dependency of the external load capacitance C_t.

As stated above, the invention is not limited to zero- or low-IF applications. After the single frequency alignment by, e.g., adjusting the gain value α, with programmable N and ω_{xtal}, the tuned LC band-pass filter 10 is tuned to each wanted frequency. Along this way, the band-pass filter 10 becomes a "frequency synthesized" filter, which is locked to "virtual oscillator frequency" $N\omega_{xtal}$, since this frequency need not be present in the IC.

The freedom to choose the value for N allows the present invention to provide a single integrated tuner circuit with arbitrary IF output. Supradyne, infradyne, zero-IF, up-conversion or one-oscillator applications can all be realized with tracking using the present invention. These applications may be provided "all-in-one" under software control using the same integrated tuner circuit.

Several other features provided by the present invention should also be noted. For example, the parasitic capacitance C_p, caused by the integrated circuit 20 itself, can be overcompensated inside the integrated circuit 20. As such, for proper tracking, a capacitor C_p, needs to be externally connected to the integrated circuit. Advantageously, the LC band-pass filter 10 can always be designed for minimum unwanted parallel capacitance and consequently maximum frequency range. Further, the fixed-frequency control loop 30 may use the X-tal oscillator frequency ω_{xtal} in the loop. This minimizes the risk of interference, since no new frequencies are introduced.

The foregoing description of various aspects of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and obviously, many modifications and variations are possible. Such modifications and variations that may be apparent to a person skilled in the art are intended to be included within the scope of the invention as defined by the accompanying claims.

CLAIMS:

1. An integrated tuner circuit, comprising:

a tuned LC band-pass filter (10) having a variable capacitance (C_t) and fixed inductance (L);

an external load capacitor having a variable capacitance (C_t); and

a fixed-frequency control loop (30) for producing a voltage (V_{TUN}) for adjusting the variable capacitances of the band-pass filter and external load capacitor to achieve tracking of the band-pass filter with an arbitrary oscillator frequency ω_{LO}.

2. The integrated tuner circuit according to claim 2, wherein the fixed-frequency control loop (30) further comprises a fixed-frequency oscillator (32) and a circuit (34) for receiving a programmable value N for setting the value of ω_{LO}, wherein the fixed-frequency control loop adjusts the variable capacitances C_t such that C_t :: $(\omega_{LO} \pm \omega_{IF})^{-2}$ :: N^{-2}, wherein ω_{IF} is an intermediate frequency.

3. The integrated tuner circuit according to claim 2, wherein the band-pass filter (10) is tuned to each of a plurality of different IF distances from ω_{LO} by adjusting the programmable value N.

4. The integrated tuner circuit according to claim 2, wherein the fixed-frequency oscillator (32) outputs a signal having a frequency ω_{xtal}, and wherein the tuned LC band-pass filter (10) is tuned to a virtual oscillator frequency ω_{LO} given by $N\omega_{xtal}$.

5. The integrated tuner circuit according to claim 1, wherein the fixed-frequency control loop (30) provides compensation for parasitic capacitance (C_p).

6. The integrated tuner circuit according to claim 5, further comprising a capacitor corresponding to the parasitic capacitance C_p in parallel with the external load capacitor.

7. The integrated tuner circuit according to claim 1, wherein the fixed-frequency control loop (30) operates to produce a signal:

$$1 - (\alpha\omega_{xtal}{}^2R^2C)N^2C_t \rightarrow 0$$

where α is a variable gain, ω_{xtal} is a frequency of a fixed-frequency oscillator, R is a resistance, C is a capacitance, and N is a programmable value for setting the value of ω_{LO}.

8. The integrated tuner circuit according to claim 7, wherein N and C_t are the only oscillator frequency dependent variables.

9. A method for tracking a LC tuned band-pass filter (10) with an arbitrary oscillator ω_{LO}, wherein the band-pass filter includes a variable capacitance C_t and a fixed inductance (L), comprising:

providing a fixed-frequency control loop (30) for producing a voltage (V_{TUN}) for adjusting the variable capacitance C_t of the tuned band-pass filter (10) and for adjusting a variable capacitance C_t of a load capacitor; and

inputting a programmable value N into the fixed-frequency control loop (30) for setting the value of ω_{LO}, wherein the fixed-frequency control loop adjusts the variable capacitances C_t such that $C_t :: (\omega_{LO} \pm \omega_{IF})^{-2} :: N^{-2}$, wherein ω_{IF} is an intermediate frequency.

10. The method according to claim 9, further comprising:

tuning the band-pass filter (10) to each of a plurality of different IF distances from ω_{LO} by adjusting the programmable value N.

11. The method according to claim 9, wherein the fixed-frequency control loop (30) includes a fixed-frequency oscillator (32) that outputs a signal having a frequency ω_{xtal}, further comprising:

tuning the band-pass filter (10) to a virtual oscillator frequency ω_{LO} given by $N\omega_{xtal}$.

12. The method according to claim 9, wherein the fixed-frequency control loop (30) provides compensation for parasitic capacitance (C_p).

13. The method according to claim 12, further comprising:

providing a capacitor corresponding to the parasitic capacitance C_p in parallel with the load capacitor.

14. The method according to claim 9, wherein the fixed-frequency control loop (30) operates to produce a signal:

$$1 - (\alpha\omega_{xtal}^2 R^2 C) N^2 C_t \rightarrow 0$$

where α is a variable gain, ω_{xtal} is a frequency of a fixed-frequency oscillator, R is a resistance, and C is a capacitance.

15. The method according to claim 14, wherein N and C_t are the only oscillator frequency dependent variables.

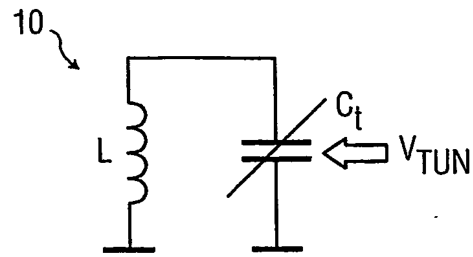

FIG. 1

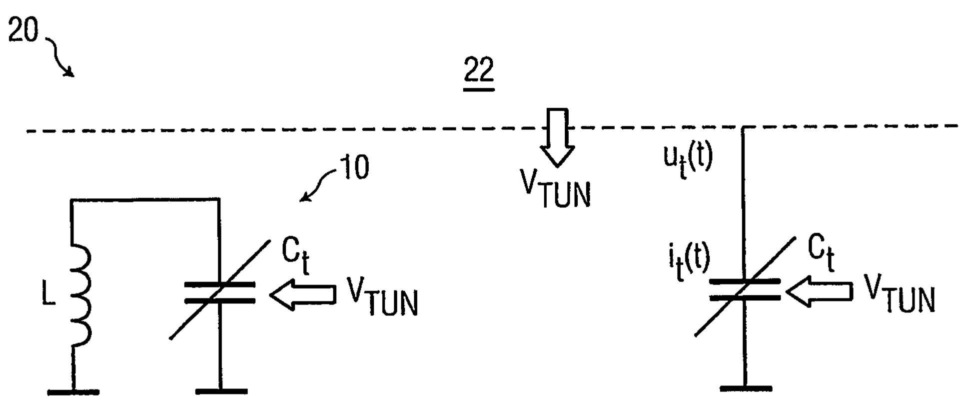

FIG. 2

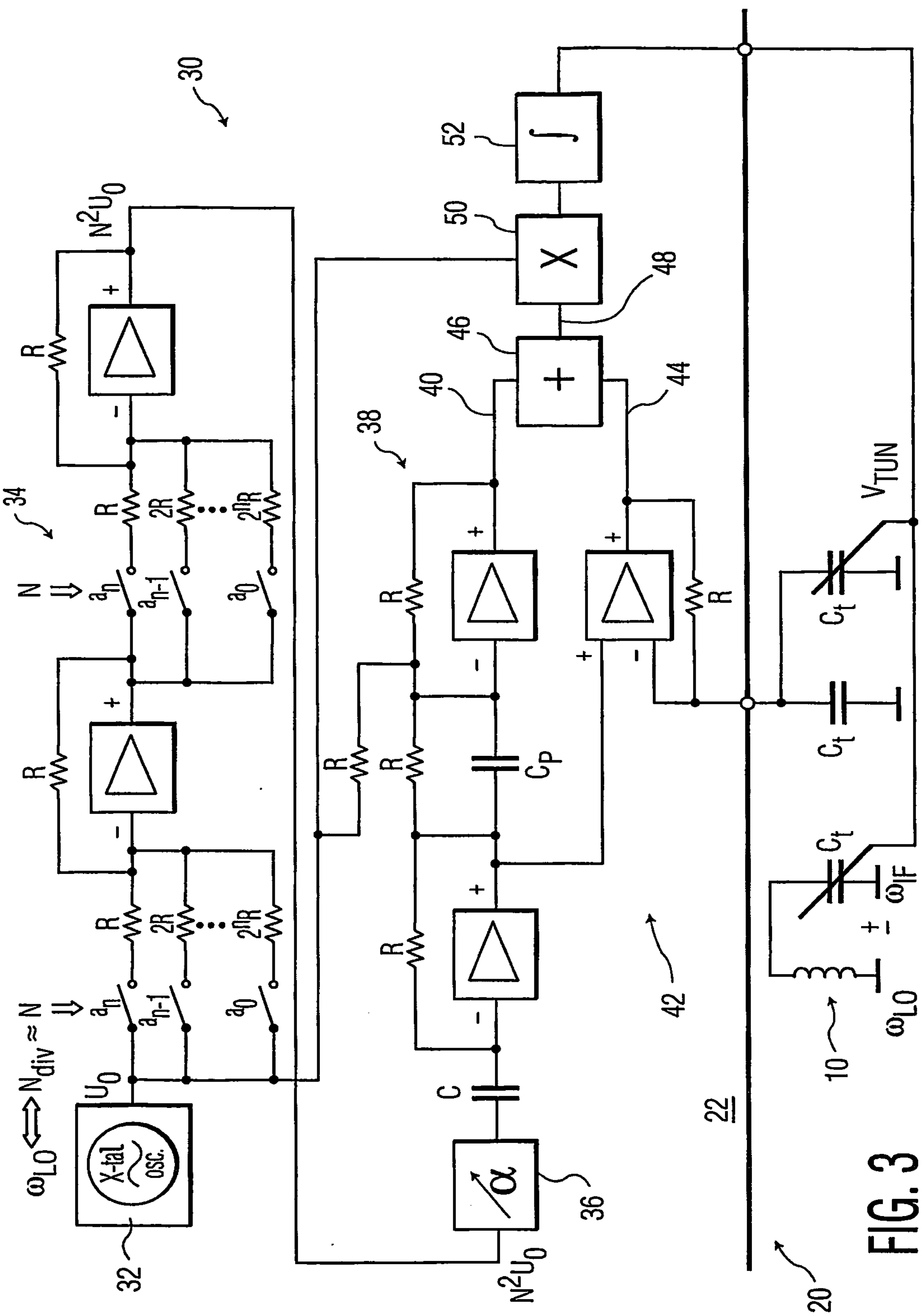
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FIG. 3

INTERNATIONAL SEARCH REPORT

International Application No
PCT[redacted]03/05503

A. CLASSIFICATION OF SUBJECT MAT[redacted]
IPC 7 H03J3/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H03J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	EP 0 766 391 A (SANYO ELECTRIC CO) 2 April 1997 (1997-04-02) column 5, line 24 - line 40; figure 2 -----	1 9
X	US 5 060 297 A (MA JOHN Y ET AL) 22 October 1991 (1991-10-22) column 5, line 1 - line 12 -----	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
1 March 2004	08/03/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Peeters, M

INTERNATIONAL SEARCH REPORT

In[illegible]tion on patent family members

International Application No
PCT/[illegible]03/05503

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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